Utility-based Approach for Video Service Delivery Optimization

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***Abstract*—This work aims to introduce an Utility-based approach for Video Service Delivery Optimization (U-VSDO). Through this optimization, a global utility function is calculated based on different constraints. Those constraints are considered based on separate utility function for each actor in the video service delivery chain (Content Provider (CP), Operator (OP) and Client (CL)). However, each actor has a global score for his vision, the overall optimization aims to satisfy the three actors. Our proposed methodology for this optimization is validated through different types of evaluation. First, a simulation based utility function is done for obtaining the optimal values of our optimization problem. Then, a complete GUI (Graphical User Interface) interface is built based on the main parameters for each actor. Finally, a test-bed is conducted to differentiate between two types of flows using open source Software Defined Network (SDN) controller. This part considered the standard use case for ETSI (European Telecommunications Standards Interface) in CDN (Content Delivery Network) as a Service.**

Keywords- CDN optimization; video service delivery; utility function, quality QoS/QoE.

I. INTRODUCTION

New video service delivery strategies face two challenges: pricing plan for the overall chain elements and the innovation for new added services. Many operators are struggling to maintain the Average Revenue per User (ARPU) and margins in revenues despite the high competition in market. They are searching for new optimizations that can achieve the balance between the main three actors in the chain (content providers, operators and consumers). But, the massive deployment of Over-The-Top (OTT) technology [1] is really representing a big threat for managed video services. Moreover, new opportunities brought by clients need to be studied in order to build a good utility between users needs and service requirements. Therefore, searching optimization algorithms and tools for managed video delivery networks is required.

The traditional Content Delivery Networks (CDNs) are not defined mainly for data centers virtualization but for data caching and services acceleration. Akamai is one of the most famous CDN multi providers over Internet as it handles almost 30% of global Internet traffic all over the world [2]. Hereinafter, we will explain the main challenges in video data centers in general and conduct a subjective comparison between the main actors in video service delivery.

A. Video Data Centers Issues

Online video uses a very large amount of storage in data centers and bandwidth (BW) over the Internet. In USA only, almost 50% of Internet BW is consumed by online videos [3]. Globally, one of the main issues in data centers is the movement of contents. We tried in a previous work to study the issue of content movement and video file optimization in terms of access cost from user perspective [4]. While, in another work, we focused on the QoE aspects and their effects on data retrieval or caching costs [5], the overall control performance especially in video services is still insufficient due to the main bottlenecks in data centers interconnections. Moreover, the more famous data centers over Internet proposed by Amazon [6] or Google [7] are suffering from the same problem of bottlenecks as reported in [3]. So, until the cloud solutions bring an improvement, there are still some drawbacks in content movements either within single data centers or between data centers. So, there are high incentives to search an optimized solution for big data movements and its optimization. New trends consider the Software defined network (SDN) solutions as a movement tool and enabler.

B. Comparison for the Three Actors

It is important to analyze the main actors in video service delivery chain. Then, we can describe the objectives of each actor in order to introduce his utility and the overall work motivations. Here, two comparisons are mandatory in order to build our utilities and have clear problem statements as follows:

1) Agility Comparison

The Agility is defined as the number of parameters and the ability of adaptation for the proposed system dynamically. So, the flexibility of service planning either for content adaptation or server placement is considered as an important factor in any video streaming chain. Thus, either for live streaming or VoD (Video on Demand), the easy adaptation and simple configuration of networks will enhance the overall system performance and users satisfactions at same time. Moreover, the correlation between the three actors in the video chain will lead to an optimal identification for both network capacities and users densities. Table I compares the Agility of the three actors effects in terms of some major attributes as follows:

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TABLE I. AGILITY COMPARISON FOR THE THREE ACTORS

Attribute	Content Provider	Operator	Client
Video Coding	The number of layers that can be available for each content like DASH layers or HLS for mobile users	The carrier has to support different tunnels of traffic and with different rates of playing videos	The client application capacity for accommodating different coding layers and buffers required
Line Speeds	Cost consumptions for high speed deployment lines to contents hosting	Fast adaptations and scalable networks for highly on demand services	Line speed constrains either for fixed rates cost or on demand bandwidth
Capacity	Maximizing the throughputs	Minimizing the network load	Maximizing the number of clients
Quality	QoS SLA/TCA between CP & OP for an efficient content delivery with min and max thresholds of quality	Quality of service measures for adaptive bit rates	Participating in QoS/QoE reports for enhancing the overall service delivery
Devices	Hardware or Software consumed for contents virtualizations or services on demand	Dynamic allocations for resources and network virtualization to cope with on demand servers caching or placements	Device capabilities to fit with different access networks and with virtual applications

2) Cost Comparison

Table II gives an overall cost comparison from each actor view as follows:

TABLE II. COST COMPARISON FOR THE THREE ACTORS

Attribute	Content Provider	Operator	Client
CAPEX cost	Min cost for content adaptations	Min transmission cost for each content	Min cost for required bandwidth line
OPEX cost	Hosting servers for different layers of same content	Running cost for QoS SLA/TCA between CP & OP	Running cost for additional Bandwidth

Based on the previous two proposed comparisons and main issues in service delivery, we can formulate our problem statements as follows:

C. Problem Statement

We propose a global optimization utility function for each one of the three actors in the video chain. As shown in Figure 1, the three actors in the chain are in collaboration for the best service delivery. Actor 1, the content provider asks Actor 2 (the operator) to deliver some video content requested by the third Actor 3 (client). We assume that the system is real time so requests can be handled through some controller unit that manages sessions and handover decisions between CDNs based on our optimization function.

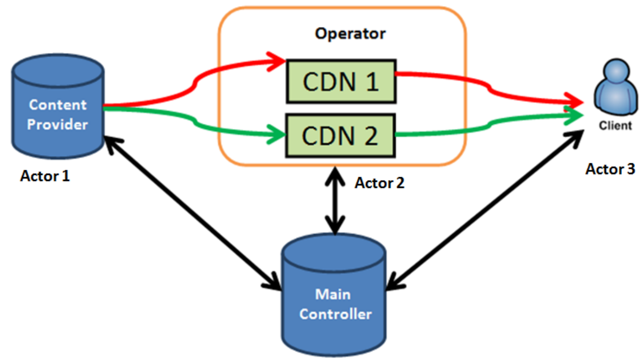

Figure 1. Main three actors in the video chain

The rest of this paper is organized as follows: Section II highlights the relevant work to this optimization and presents the different categories in video service delivery optimization. Then, Section III introduces our proposed methodology based on the new utilities constrains. The evaluation for our proposal is conducted in Section IV. Finally, this research is concluded with some future directions in Section V.

II. RELATED WORK

We can divide contributions for optimizing video delivery into three main methods: *i) the network-centric approach*, in which decisions are made at the network side (mainly by network operators), *ii) the user-centric approach* making the decision based on the user's benefit, and *iii) the context-centric approach*, where the switching decision is made by considering different context information.

i) The *network-centric*:

In this approach, decisions are made by the operators and they are principally based on their benefits.

Sylvia et al. [8] propose a distributed strategy to get network topology information, and use Internet Control Message Protocol (ICMP) ping method to measure Round-Trip Time (RTT), in order to switch to a network which has the lowest RTT. Xueying et al. [9] work on the load balancing algorithm which automatically selects network candidate based on local resource conditions. The main advantage of this method is the network resources optimization. But these techniques do not consider content provider expectations and users Quality of Experience (QoE).

ii) The user-centric:

Network switching is made in order to satisfy user's benefits, without considering network load and content provider expectations. Ksentini et al. [10] consider Quality of

Experience measurements over different access types. After predicting a Mean Opinion Score (MOS) with Pseudo Subjective Quality Assessment (PSQA), a vertical handover (change in access network) is carried out towards the network offering the best MOS. It can be noticed that the user-centric approach has the main drawback from a load balancing perspective, since users generally consider only their own benefits while making decisions and letting the Operator and Content Provider benefits.

iii) The context-centric approach:

In this approach, the delivery decision optimization is made by considering different contexts (Content Provider, Operator, and Client). Bogdan et al. [11] propose an algorithm, called Smooth Adaptive Soft-Handover Algorithm (SASHA). Its goal is to improve the user perceived quality while roaming through heterogeneous wireless network environments. The score of each connection is evaluated based on a comprehensive Quality of Multimedia Streaming (QMS) including the following metrics: QoS (Quality of Service), QoE (Quality of Experience), Cost, Power efficiency and user preferences. The idea is to adapt delivery in the network that has the best (QMS) score. The disadvantage is the no consideration of content provider expectations in the adaptation process.

Suciu et al. [12] propose Hierarchical and Distributed Handover (HDHO) method, a distributed handover decision framework which takes into account the objective of Content Provider by considering the content requirements in terms of resources, Operator in terms of network load and user preferences by considering cost sensibility. Even if, this proposal takes into account the aim of each actor on the delivery chain, some relevant parameters are omitted. In content provider side the cost of transmitting the content in a network is missed, in network side the cost and hardware status are absent, in client side the perceived quality of experience is not taken into account.

In order to maximize a perceived quality of experience in users' side, respect conditions of content providers and the operators' benefits, we need to define a new video delivery optimization which takes into account the objective of each actor. Moreover, in such a dynamic environment composed by different devices with different characteristics, variables network conditions with different cost/load and content providers with different expectations, we propose the U-VSDO algorithm that handles all those parameters as explained in the next section.

III. Proposed Methodology

The purpose of this section is to explain the steps of the optimization approach which takes into account the objective of Content Provider (CP), Operator (OP) and the User. Our approach is based on the definition of three entities, each with their goals as follows:

- The objective of Content Provider is to send the Content in the network with a minimum cost and still manage the Content expectations in terms of requirements (for example the minimum required throughput for the content).
- The objective of the Operator is to transmit content on its network (CDN1 or CDN2 in our example) while keeping the load as lower as possible.
- The objective of the client is to improve the Quality of Experience besides the QoS.

The Utility-based Video Service Delivery Optimization (U-VSDO) will take into account the goals of each actor in addition to the main constrains. As shown in Figure 1, the optimization decision will be managed by the Main Controller after solving the optimization problem. This controller can be for example an SDN controller as will be explained in Section IV for SDN Network Function Virtualization NFV [13]. So, we can solve the problem by the following steps:

A. Problem Formulation

We used the utility functions to calculate the scores of each actor; this is very useful to characterize the satisfaction derived from a parameter.

The function must have the following characteristics:

- The function increases with parameter x and has a maximum of 1,
- When x is "low", the function tends to zero.
- The possibility to have normalized results between [0, 1].

Several functions meet these criteria. Moreover, we decided to use the utility function: ($1- e^{-x}$), as the work in [12] [14], where x is a parameter of the function. In future work, we will further investigate the influence of others utility functions in our optimization problem.

Hereinafter, we introduce the details of each actor utility function based on the previous propositions either for utility type or normalization way. Then, a global score utility will be calculated under the main constrains defined for each actor as follows.

As the work in [12], we have two types of parameters:

- The positives parameters: High values are better, example (throughput, available hardware, etc.), then for an utility function we took the parameter directly.
- The negatives parameters: Low parameters are better, example (cost, network load, etc., then for these parameters we choose $\frac{1}{\text{cost}}$ for example.

- ***For Content Provider:***

$$S_{cp}(i,j) = (1 - e^{-\frac{1}{C_{cp}(j)}} + 1 - e^{-Dr(i)})\,.\,C_{cps}\,.\,Ds \qquad (1)$$

$$S_{cp}(i,j) = (2 - e^{-\frac{1}{C_{cp}(j)}} - e^{-Dr(i)})\,.\,C_{cps}\,.\,Ds \qquad (1)$$

where:

- $S_{cp}(i,j)$, is the score related to Content Provider (CP) for flow j in network i.
- C_{cp} = UNIT cost per Mbyte, is the cost of transmitting the content in the network (CDN1 or CDN2) in our example).
- C_{cps} = (C_{cpmax}(j),$C_{cp}(j)$) = 0, when $C_{cpmax} < C_{cp}$, S_{cp}= 0.
- C_{cpmax}, is the maximum cost that the content provider is ready to pay.
- D_r, is the available throughput.
- Ds = (D_{ref} (j) ,D_r (i)) =0, when $D_{ref} < D_r$
- D_{ref}, is the required video throughput.

Note that: (A, B) means that; when A < B then (A,B) =0 and 1 otherwise.

- ***For Operator:***

$$S_{op}(i) = (3 - e^{-\frac{1}{Cop\,(i)}} - e^{-\frac{1}{NL(i)}} - e^{-H(i)}).NLs.Cops.Hs \quad (2)$$

where:

- $S_{op}(i)$, is the score related to Operator in network i.
- $Cop = Opex + Capex$; is the cost from the operator side.
- NL , is the network load.
- *NLs*=($NL_{max}(i)$, *NL (i)) =0, when* $NL_{max} < NL$
- NL_{max}, is the maximum acceptable network load.
- *Cops= (*$Cop_{max}(i)$*,Cop(i))=0, when* Cop_{max}*< Cop*
- Cop_{max}, is the maximum price that the operator is ready to invest.
- *H* is the required hardware threshold.
- *Hs= (H(i),* H_{min}*(i)) = 0, when* $H < H_{min}$
- H_{min}, is the minimum required hardware for considered service.

- ***For Client :***

$$S_{Cl}\,(i,j) = \frac{MOS_{NET}\,(i,j)}{S_{max}} \quad (3)$$

where:

- MOS_{NET} (i,j) corresponds to the satisfaction obtained by users in network i for flow j. It is a parametric model which computes the Quality of Experience function of contexts information (environment) [15], the model takes into account parameters such as the device type, the video content type and the quality of the network link in order to predict the Quality of Experience. The analytical function is called MOS_{NET} and is presented in the equation below:

$$MOS_{NET}(i,j) = A + B * e^{-C*\frac{Dv(j)}{Dr(i)}} \quad (4)$$

- *A*, *B* and *C:* are the model parameters calculated by using subjective test data from different experiments.
- S_{max} , is the maximum value of MOS_{NET} which correspond to the normalized factor

So, the general optimization problem can be formulated as follows by total score:

$$S_T = \alpha * S_{cp} + \beta * S_{op} + \mu * S_{Cl} \quad (5)$$

where : α, β, μ are the weights of entities in the global optimization and : $\boldsymbol{\alpha + \beta + \mu = 1}$

The weighting parameters define the importance of each actor in the optimization decision. In our work we decided that the Content Provider, the Operator and Users have the same weight, then: $\boldsymbol{\alpha = \beta = \mu = \frac{1}{3}}$

B. Optimization Problem Constraints

In this section, we summarize the main utility functions for the computed scores and their constraints that will be implemented in the next section and appeared in the GUI interface as follows:

$$Content\ Provider : S_{cp}(i,j) = 2 - e^{-\frac{1}{Ccp(j)}} - e^{-Dr(i)}$$

$$Operator : \quad S_{op}(i) = 3 - e^{-\frac{1}{Cop\,(i)}} - e^{-\frac{1}{NL(i)}} - e^{-H(i)}$$

$$Client : \qquad S_{cl}(i,j) = \frac{Aj + Bj * e^{-Cj*\frac{Dv(i)}{Dr(j)}}}{S_{max},j}$$

Objective: $\boldsymbol{maximize\ (\alpha * S_{cp} + \beta * S_{op} + \mu * S_{cl})}$

Subject to : $C_{cp} < C_{cpmax}$
$C_{op} < C_{opmax}$
Dr < Dref
NL< NL_{max}
$H_{min} < H$

IV. IMPLEMENTATION AND EVALUATION

To validate our work, we propose two ways. First, we are going to optimize the utility function parameters through a simulation tools using Matlab. Then, the decision output of this optimization will take the form of graphical interface for doing many scenarios. Second, we will do a testbed for decision making based software defined network (SDN) solution to differentiate between CDNs caching. This solution conforms to the ETSI solution use case 8 for virtual CDN-as-a-service [13].

A. Validation Based Simulation

The validation based simulation has been conducted based on some real test captured from last championship Roland Garros (RG) [16]. Roland Garros is a major tennis tournament held over two weeks between late May and early

June 2013 at the Stade Roland Garros in Paris, France. Some analysis has been proposed in our previous work [17]. In this work, we studied and analyzed users engagement during this event based on some real time measures done based on the Orange platform. Then, we will extend the study and the analysis to conform to the three actors in video. Samples from the RG tests are shown in the following Table III. Parameters such as buffering time, startup time and playing time are considered.

TABLE III. SAMPLES FROM ROLAND GARROS MEASURES

Buffering ratio (%)	Startup time (Seconds)	Average encoding (kbps)	Playing time (seconds)
0,84375	2,671875	807,0869565	446,85
1,1761176	0,8860886	973,3505747	3600,33
0,785625	0	970,070922	1521,11
1,15	0	963,8943089	1356,33
2,734375	0,59375	2040,769811	2791,39
0,682039	0,6560375	945,2185792	1938,35
0,5624928	0,8281144	955,7608696	455,50

We implemented a complete Graphical Tool (GT) to be used by the operators in their networks design and optimization. This graphical tool is built based on Matlab code.

Figure 2 illustrates the main construction steps as divided into two parts:

- Creating general parameters: which means defining the basic topology elements and factors in the three actors (CP, OP and CL) i.e. the main profiles for each video and CDN.
- Calculating results: Calculating the general score for all actors and show the selected CDN as best path for video profile.

Actually, we simulate the global utility function and calculate the scores for different networks for our approach U-VSDO. Moreover, and in order to facilitate the decision making output by each operator running our methodology, we developed a GUI interface to cope with the three utility functions for the three actors main parameters as shown in Figure 2.

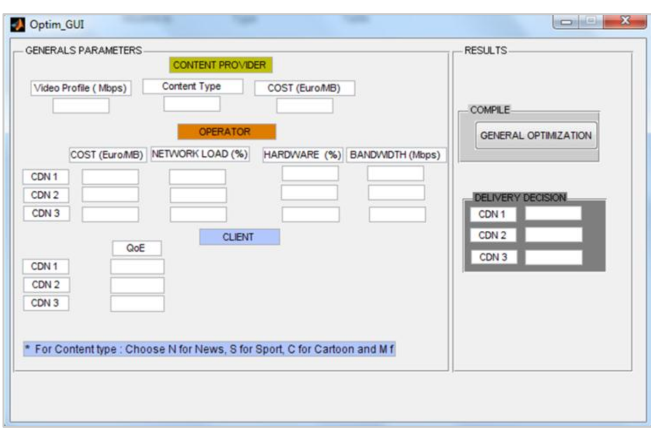

Figure 2. GUI interface for U-VSDO approach

After finishing this simulation, we conducted a brief comparison between our approach U-VSDO and other similar techniques that used utility functions for decision making based multimedia handover like SASHA [11] and HDHO [12]. The results indicated in Table IV highlighted the main parameters considered as supplementary by our approach U-VSDO over other ways.

TABLE IV. COMPARISON BETWEEN U-VSDO TO OTHER APPROACHES

	SASHA	HDHO	U-VSDO
OP cost	x	x	√
CP cost	√	√	√
Content Type	x	x	√
Device Type	x	x	√
Client Type	x	x	√
Network Load	√	√	√
H/W Status	x	x	√

Finally, Figure 3 represents the correlation between this work and our previous work [17] for different types of media tested under our approach. Figure 3 handled different types of videos (News, Sport, Music and Animation) in terms of which CDN can achieve high scores in order to satisfy user engagement and all actors' satisfactions for our methodology.

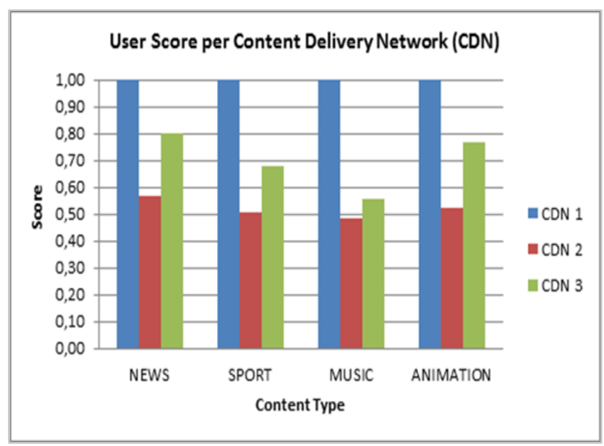

Figure 3. User score for different types of media to different CDNs

B. Validation Based Testbed

In this part, we try to validate our approach using software defined network controller through the SDN implementations based testbed. The testbed architecture is shown in Figure 4. We simulate the traffic source as video on demand servers by VOD1 & VOD2 (using VLC Servers for same contents but on different format: one Standard Definition (SD) and the other High Definition (HD)) and the client will also use a VLC client.

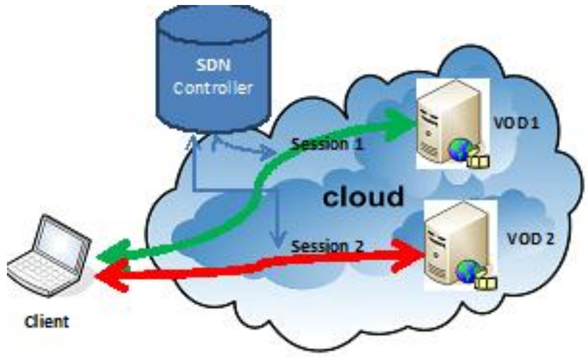

Figure 4. Proposed testbed architecture

The experiment for simulating SDN controller is done using Mininet open source package [18]. Using this package, we can build a complete architecture of virtual topology (including VM clients, VM servers, Virtual Open switch and the session controller based an OpenFlow [19]).

As SDN offers Networking-as-a-Service (NaaS) and Network Function-as-a-Service (NFaaS), the main objective is to measure the performance in case of obtaining the contents from VOD1 (SD) and due to the QoE index; the session will be transferred to VOD2 (HD) for same contents. Also, we can see that this is a type of session based hijacking using SDN controller. The response time for sessions hijacking is calculated for different types of video bit rates as shown in Figure 5. As shown in this figure, the switching time is acceptable for different types of videos and is conform with the ITU recommendations for quality of streaming.

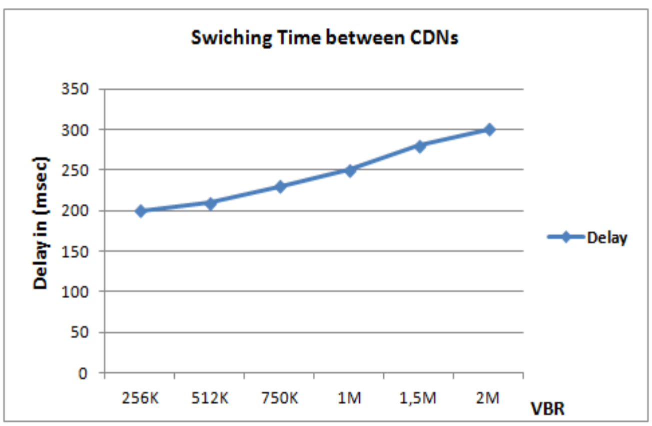

Figure 5. The response time for sessions hijacking against VBR (video bit rate) as measured during the experiment.

V. CONCLUSION

An optimization mechanism is presented and evaluated. It solves the utility function optimization for the three common actors in video streaming chain (CP, OP and CL) for any data centers, including their roles and objectives in video chain. The proposed methodology U-VSDO is evaluated by two ways. First, through a simulation for global utility function and our approach gave good results compared to other methods like HDHO or SASHA in terms of value added parameters in decision making. Secondly, a testbed is evaluated to validate the CDN-as-a-Service controlled by an SDN controller and the consumed time for sessions hijacking is measured for different video bitrates.

In the next work directions, we will consider the real-time video service optimization based on adaptive technique suitable for the real-time nature.

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